The Aggregate-Disaggregate-Aggregate (ADA) Freight Model System

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1. Introduction

Disaggregate models – defined here as models using observations at the level of the traveller, the travelling group, the business establishment or the shipment - have several advantages over aggregate models (which use groupings of those units as observations, e.g., groupings by geographic zone). Disaggregate models can be based on a foundation in behavioral theory, can include more detailed policy-relevant variables, and do not suffer from the aggregation biases of aggregate models. Nevertheless, there are perfectly valid reasons why some of the components of a model system are modeled in an aggregate fashion. In this paper, we propose an **aggregate-disaggregate-aggregate** (ADA) model system for freight transport.

The ADA model system is a transport model system at the international, national or regional scale, designed by or for public authorities. International, national and regional freight transport models are used for different purposes, including:

- Forecasting transport demand (and through this, emissions from traffic, traffic safety, etc.) in the medium to long run under various scenarios;
- Testing transport policy measures, such as road user charging;
- Predicting the impacts on traffic (and traffic-related measures as mentioned above) of the provision of new infrastructure (roads, railway lines, canals, bridges, tunnels, ports and public freight terminals).

In the ADA model system, the production to consumption (PC) flows and the network model are specified at an aggregate level for reasons of data availability. Between these two aggregate components is a logistics model that explains the choice of shipment size and transport chain, including mode choice for each leg of the transport chain. This logistics model is a disaggregate model at the level of the firm, the decision making unit in freight transport.

Most (inter)national or regional freight transport model systems are lacking logistics elements, such as the the determination of shipment size or the use of distribution centers. Exceptions are the SMILE and SMILE+ model in The Netherlands (Tavasszy et al., 1998, Bovenkerk, 2005), the SLAM model for Europe (SCENES Consortium, 2000), the EUNET 2.0 model for the Pennine Region in the UK (Yin et al, 2005), the model for Oregon (Hunt, 2003, Hunt et al., 2001, PbConsult, 2002) and the work of Liedtke (2005), which includes an application to German long-distance markets.

Section 2 of the paper explains the structure of the ADA model system. The various components of this model system are treated in section 3, focusing on the disaggregate ("middle") part of the ADA system (the logistics model) and on the disaggregation that comes immediately before the disaggregate part and the aggregation that comes direcly after it. The logistics model's data requirements are discussed in section 4. Estimation/calibration and validation issues for the logistics model are discussed in section 5. These first five sections present the model system in general terms. In section 6, an application of the ADA model for the national freight transport model system of Norway and Sweden is presented. Finally, a summary and conclusions are provided in section 7.

2. The ADA model structure

2.1 The general concept

The ADA model system includes, first, an aggregate model for the determination of PC flows, then a disaggregate "logistics" model, and, finally, an aggregate network assignment model. The relation between the first aggregate part (PC flows) and the disaggregate part is further treated in section 2.2, and in section 2.3 the boundary lines between the disaggregate logistics model and the aggregate network assignment are discussed.

Figure 1 is a schematic representation of the structure of the freight model system. The boxes indicate model components. The top level of figure 1 displays the aggregate models. Disaggregate models are at the bottom level.

The model system starts with the determination of flows of goods between production (*P*) zones and consumption (*C*) zones (retail goods for final consumption; and further processing of goods for intermediate consumption). These models are commonly based on economic statistics (production and consumption statistics, input-output tables, trade statistics) that are only available at the aggregate level (with zones and zones pairs as the observational units). Indeed, to our knowledge, no models have been developed to date that explain the generation and distribution of PC flows at a truly disaggregate level.

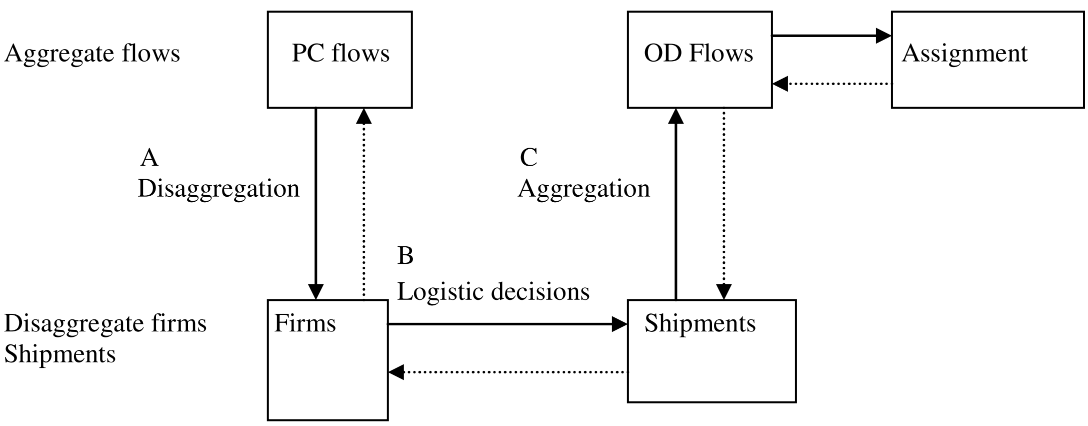

Figure 1. ADA structure of the (inter)national/regional freight transport model system

Most existing freight transport model systems include submodels for generating PC or OD matrices (possibly by mode) and routines for assigning either one of these matrices to the networks (unimodal or multimodal). As explained in section 2.2, assignment of PC flow to the networks would be incorrect. In ADA, a new logistics model takes as input the PC flows and produces OD flows for network assignment. The logistics model consists of three steps:

A. Disaggregation to allocate the flows to individual firms at the *P* and *C* end;

B. Models for the logistics decisions by the firms (e.g., shipment size, use of consolidation and distribution centers, modes, loading units, such as containers);
C. Aggregation of the information per shipment to origin-destination (OD) flows for network assignment.

This model structure allows for logistics choices to be modeled at the level of the actual decison-maker, along with the inclusion of decision-maker attributes.

The allocation of flows in tons between zones (step A) to individual firms are, to some degree, based on observed proportions of firms in local production and consumption data, and from a registry of business establishments. The logistics decisions in step B are derived from minimization of the full logistics and transport costs (to be modeled as a random cost choice model).

The aggregation of OD flows between firms to OD flows between zones provides the input to a network assignment model, where the zone-to-zone OD flows are allocated to the networks for the various modes. Assignment can, in principle, be done at the level of individual vehicles (microscopic or mesoscopic models for simulating route choice, see Ben-Akiva et al., 2007; the Oregon model also is structured with assignment at the level of individual vehicles). In such cases, the ADA model would be an ADD (aggregate-disaggregate-disaggregate) model (see fig. 2).

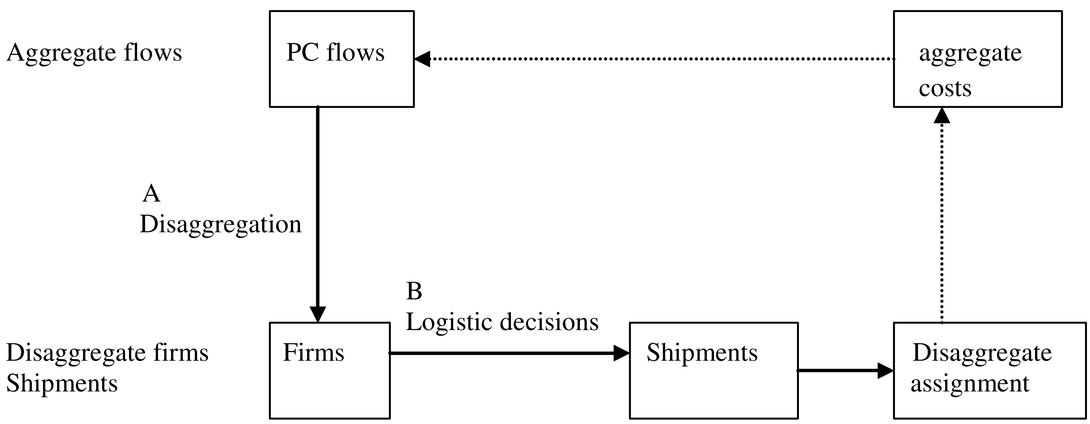

Figure 2. Proposed ADD structure of the (inter)national/regional freight transport model system

Most model systems perform an assignment of aggregate zone-to-zone flows (possibly with several user classes) to the networks in order to use available software to keep the model tractable and to keep the run time manageable. This approach is also used because the network level is the level at which validation/calibration data are usually available (e.g., traffic counts at various locations/screenlines). On the other hand, vehicle-level data that can be used for the estimation of micro-level network models are becoming more common.

There are also be backward linkages, as seen in figure 1 (the dashed lines). The results of network assignment are used to determine the transport costs that are part of the logistics costs which are minimized in the disaggregate logistics model. The logistics costs for the various OD legs are summed over the legs in the PC flow (and aggregated to the zone-to-zone level by an averaging over the flows). These aggregate costs can then be used in the model that predicts the PC flows (for instance, as part of the elastic trade coefficients in an input-output model). In the case of assignment of individual vehicles in an ADD model, aggregate transport costs can be calculated at the PC level by adding the costs of the different vehicles that are involved in the same PC chain, and then averaging over the PC flows (fig. 2, dashed lines).

2.2 Relation between the PC flows and the logistics model

The PC flows between the production locations *P* and the consumption locations *C* are given in tons by commodity type. The consumption locations refer to both producers processing raw materials and semi-finished goods and to retailers. The logistics model serves to determine which flows are covered by direct transports and which transports will use ports, airports, consolidation centers (CCs), distribution centers (DCs) and/or railway terminals. It also gives the modes and vehicle types used in transport chains. The logistics model, therefore, takes PC flows and produces OD flows. An advantage of separating out the PC and the OD flows is that the PC flows represent what matters in terms of economic relations -- the transactions within and between different sectors of the economy. Changes in final demand, international and interregional trade patterns, and in the structure of the economy, have a direct impact on the PC patterns. Also, the data on economic linkages and transactions are in terms of PC flows, not in terms of flows between producers and trans-shipment points, or between trans-shipment points and consumers.

Changes in logistics processes (e.g., the number and location of depots) and in logistics costs have a direct impact on how PC flows are allocated to logistics chains, but only indirectly (through the feedback effect of logistics choices and network assignment) impact the economic (trade) patterns. Assigning PC patterns to the networks would not be correct. For instance, a transport chain road-sea-road would lead to road OD legs ending and starting at ports instead of a long-haul road transport that would not involve any ports. A similar argument holds for a purely road-based chain that uses a van first to a consolidation center, then is consolidated with other flows into a large truck, and, finally, uses a van again from a distribution center to the *P* destination. In this scenario, The three OD legs might be assigned to links differently than would be the case for a single PC flow. Therefore, adding a logistics module that converts the PC flows into OD flows allows for a more accurate assignment. The data available for transport flows (from traffic counts, roadside interviews and interviews with carriers) also are at the OD level or screenline level, not at the PC level.

2.3 Relation between the logistics model and the network assignment

In several existing freight transport model systems, a deterministic network model carries out both the modal split and the network assignments (in a multimodal assignment). If the assignment in the ADA model system is multimodal, the logistics model does not need to predict mode choice. The mode choice would be determined as a deterministic optimization. This is labelled Option II in figure 3. A better approach would be to include mode choice in the logistics model, and restrict the assignment to be unimodal. In the latter approach, the mode choice would be determined in a stochastic way, together with the other logistics choices (e.g., shipment size, number of legs in a transport chain, terminals used). This is Option I in figure 3. The outputs of the logistics model will then be in terms of vehicle or vessel flows (not just tons) between OD pairs.

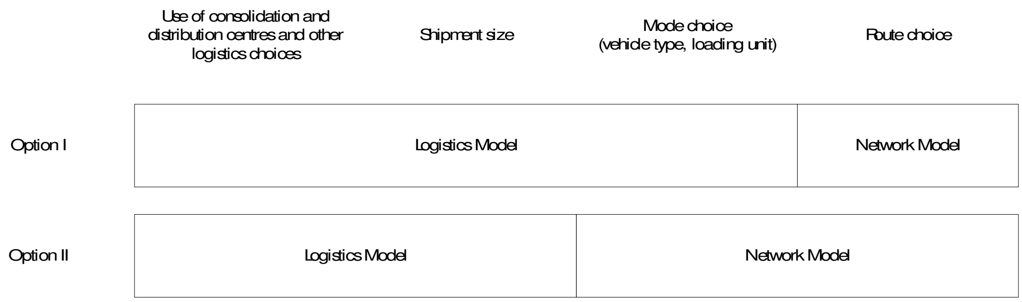

Figure 3. Two options for combining the logistics and the network model

3. Model specification

Each component of the ADA model is discussed in section 3: generation of PC flows; logistics model in three steps; and assignment. Additional detail on the logistics model can be found in de Jong and Ben-Akiva (2007)

3.1 Generation of PC flows at the aggregate level

The type of model used here can be a multi-regional input/output (MRIO) model or a regionalized national input/output model (Cascetta, 2001; Marzano and Papola, 2004; Hunt and Abraham, 2005), or a spatial computable general equilibrium (SCGE) model (Bröcker, 1998; Tavasszy et al., 2002; Ivanova et al., 2002). Input data required for these models are input-output statistics (preferably multi-regional), production and consumption statistics by economic sector and international trade statistics.

3.2 The logistics model

In section 3.2 the three steps (A, B and C; see figure 1) of the logistics model are discussed.

3.2.1 Disaggregation to firm-to-firm flows (step A)

Step A in the logististics model (conversion of zone-to-zone flows to firm-to-firm flows) is not a choice model, but, rather, a prerequisite so that logistics choices can be captured at the actor level. Instead of modeling trade between zones, this step makes possible modeling trade between firms. These firms are manufacturers, wholesalers or retailers.
The aggregate representation of the PC flows that are produced by the first aggregate model of the ADA system, and that are input to the disaggregation step A, is as follows:
<u>Flows of goods in tons per year, by:</u>
- *r*, zone of the sender (production zone)

- *s*, zone of the receiver (consumption zone)
- *k*, commodity type.

Step A creates a disaggregate representation, characterized by:
<u>Flows of goods in tons per year, by:</u>
- *m*, sending firm (located in zone *r*)
- *n*, receiving firm (located in zone *s*)
- *k*, commodity type.

Three general approaches to generate a disaggregate population or sample of firm-to-firm flows may be distinguished:

1. Re-weighting -- use an existing sample or population and re-weight using marginal distributions (i.e., the row and column totals);
2. Synthetic -- draw from a sequence of conditional distributions;
3. Hybrid -- begin with re-weighting and enrich the set of characteristics using synthetic draws.

The re-weighting approach is the simplest, but a sample of actual firm-to-firm flows is only rarely available. The U.S. and Sweden have a Commodity Flow Survey (CFS) sample, but these are samples of shipments for a limited time period (e.g, one to three weeks in Sweden). In this case, we are looking for all supplier/receiver pairs on an annual basis. Therefore, in practically all aplications, a synthetic or a hybrid approach for step A is developed. See Annex I for an example of how this approach may be implemented.

3.2.2 The logistics decisions at the disaggregate level (step B)

Step A produces disaggregate supplier-receiver relations (a business relation between two firms in which one is the sender of a good and the other the receiver). Each relation has an annual flow of goods in tons by commodity type. Even for a small area, there are millions of such relations. To reduce runtime, firm-to-firm relations are sampled, and expansion factors are used to obtain population estimates. For each relation, step B simulates the logistics decisons (micro-simulation) and adds the outcomes of these to the level of a firm-to-firm relation.

The different logistics decisions included in step B are:
- Frequency/shipment size (so inventory decisions are endogenous);
- Choice of loading unit (e.g., containerized or not);
- Use of distribution centers, freight terminals, ports and airports, and the related consolidation and distribution of shipments. The locations of these trans-shipment points are assumed as given, what is determined here is their use. This also gives the number of legs in the transport chain;
- Mode used for each leg of the transport chain. The choice set may contain: air transport, road transport, rail transport and maritime transport (possibly each with different vehicle/vessel types).

Step B of the logistis model adds dimensions to the disaggregate representation that was produced by step A. The full disaggregate representation after step B, consists of:
<u>Shipments of goods in number of shipments, tons, ton-kilometers and vehicle/vessels per year, by:</u>

- *m*, sending firm (located in zone *r*)
- *n*, receiving firm (located in zone *s*)
- *k*, commodity type
- *q*, shipment size
- *l,* transport chain type (number of legs, mode and vehicle/vessel type used for each leg, terminals used, loading unit used).

The basic mechanism in the model for decison-making on all these choices is the minimization of total logistics costs. The total annual logistics costs *G* of commodity *k* transported between firm *m* in production zone *r* and firm *n* in consumption zone *s* of shipment size *q* with transport chain *l* (including number of legs, modes, vehicle types, loading units, trans-shipment locations) are:

$$G_{rskmnql} = O_{kq} + T_{rskql} + D_k + Y_{rskl} + I_{kq} + K_{kq} + Z_{rskq} \quad (1)$$

Where:

- G: total annual logistics costs
- O: order costs
- T: transport, consolidation and distribution costs
- D: cost of deterioration and damage during transit
- Y: capital costs of goods during transit
- I: inventory costs (storage costs)
- K: capital costs of inventory
- Z: stockout costs

In this minimization, it is assumed that the subscripts for the specific firms *m* and *n* (and also, for instance, firm size) do not matter. This assumption may be relaxed to accommodate economies of scale in warehousing, ordering and transport. Also, variation in the discount rate for the inventory capital costs and of other preferences between firms may be included.

The purchase costs of the goods from different suppliers are not part of the optimization, since the senders and receivers of the goods have already been determined in step A. However, the purchase costs do play a role through the capital costs of the goods that are included in the equation above.

Equation (1) is expanded as follows: (see RAND Europe et al, 2004; RAND Europe and SITMA, 2005):

$$G_{rskmnql} = o_k.(Q_k/q_k) + T_{rskql} + i.j.g.v_k.Q_k + (i.t_{rsl}.v_k.Q_k)/365 + (w_k + (i.v_k)).(q_k/2) + a\ .\ ((LT.\sigma_{Q_k}^2)+(Q_k^2.\sigma_{LT}^2))^{1/2} \quad (2)$$

Where:

- : the constant unit cost per order
- Q: the annual demand (tons per year)
- q : the average shipment size
- i: the discount rate (per year)
- j: the fraction of the shipment that is lost or damaged (might vary between modes)

- g: the average period to collect a claim (in years)
- v: the value of the goods that are transported (per ton)
- t: the average transport time (in days)
- w: the storage costs per unit per year
- a: a constant to set the safety stock in such a way that there is a fixed probability of not running out of stock. For medium/high frequency products, a common assumption is that the demand (and lead-times) follows a Normal distribution. *a* will then be: $a = F^{-1}(CSL)$, where F^{-1} is the inverse Standard Normal Distribution and *CSL* is the cycle service level, which is the probability that the stock will not be empty during a replenishment cycle.
- LT: expected lead-time for a replenishment (time between placing the order and replenishment)
  σ_{LT}: standard deviation for the lead-time
- σ_{Q_k} : the standard deviation for the yearly demand

The optimal shipment sizes in the standard cases are not influenced by the safety stock, or vice versa. However, different transport alternatives with different transit times have an impact on the safety stock through the lead-time (and possibly through the standard deviation of the lead-time), and, thereby, also impact the inventory cost (and the total cost). This may be the case for alternative modes. In principle, lead-time should be a function of the mode (h): LT = LT(h).

3.2.3 Aggregation to zone-to zone flows (step C)

In step C of the logistics model, shipments for the same commodity type are aggregated to obtain OD flows in vehicles (not in tons).

The aggregate representation that is produced in step C is as follows:
<u>Flows of vehicle/vessel units per year, by:</u>
- *r*, origin zone (production zone or zone used for trans-shipment)
- *s*, destination zone (zone used for trans-shipment or consumption zone)
- *k*, commodity type (and distinguishing empty vehicles)
- *v*, mode (e.g., road transport) or vehicle/vessel type (e.g., heavy truck).

If the disaggregation was done properly, and if step B has not introduced errors, this is simply a matter of straightforward summation over shipments. However, the consistency issue in total flows between steps A and C should not be overlooked. If the disaggregation in step A is done by Monte Carlo simulation, or if the logistic decisions in step B are done by assigning discrete categories on the basis of random draws from some distribution, the total flows in C may not add up to what we started with in step A. Consistency can be guaranteed if all sub-steps in step A and B are allocations of given totals (possibly on the basis of random draws), instead of the generation of new patterns that only approximate the original aggregate PC flows. More on the consistency of aggregation and disaggregation (in the context of dynamic traffic management systems) can be found in Bierlaire et al. (2000).

Empty vehicle flows are calculated as follows: the loaded trips are first calculated as described above, and then vehicle balances are used to let vehicles return from where they came, with specific shares for empty and loaded return trips. In this formulation, the probability that some of the empty capacity will also be used for transporting goods in the opposite direction is taken into account.

3.3 Assignment to networks

Standard aggregate network assignment software can be used to carry out an assignment of vehicles or tons (ADA model), or a (less standard) disaggregate assignment (ADD model). The latter is usually a simulation-based procedure, where individual vehicles are loaded one-by-one onto the network. This simulation can be microscopic, and includes all the movements of each vehicle on the network in detail (e.g., including lane changes) or mesoscopic, where more aggregate relationships (such as speed-density curves) are used to mode individual vehicle movements (see Ben Akiva, et al., 2007).

4. Data requirements

For the logistics model presented, the following data are needed for step A (disaggregation from flows to firms):

1. The number of firms (or the local units for firms with multiple establishments) by commodity type and zone.
2. The turnover of these local units and/or the number of employees of these firms.

This information is required both at the production and the consumption end. Another requirement is the consumption pattern (in terms of the commodity classification used) of the firms by commodity type produced. We assume that each firm (local unit) will produce goods in only one commodity class, but it may consume goods from several commodity groups.

Step B (logistic decisions) requires information on the following items:

1. Data on individual shipments: sector of sender and receiver, origin and destination, value of the goods, modes and vehicle/vessel type and size used, cargo unit, shipment size/frequency, use of freight terminals (including intermodal terminals and marshalling yards), consolidation and distribution centers, ports and airports. Preferably this is transport chain information: which shipments go directly from *P* to *C*, which use the above intermediate points?
2. Data on the location of the freight terminals, consolidation and distribution centers, ports and airports;
3. Data on transport and logistics costs: transport costs per km, terminal costs, handling and storage costs for all available alternatives.

Most crucial are the data on the shipments of individual firms (item 1 for step B above). The spatial detail needs to be that of the zones used in the model. Step C requires no extra information.

5. Estimation, calibration and validation

We distinguish between model estimation (which uses disaggregate data and formal statistical methods), model calibration (which takes place on aggregate data and may or may not involve formal statistical methods) and validation (which takes place after having done the assignment and involves a comparison with traffic count data).

Figure 4 represents an estimation, calibration and validation process for the ADA model system for freight transport. The estimation and calibration data are shown above the boxes, while the validation data are below the boxes. The matrices of PC flows are usually partly based on observations and partly synthetic (model-generated). The data used in this process comes from a CFS, regional input-output systems, economic statistics from national accounts and foreign trade data. The logistics model is estimated on a CFS or similar disaggregate data, coupled with information on terminals and time and costs data from the networks.

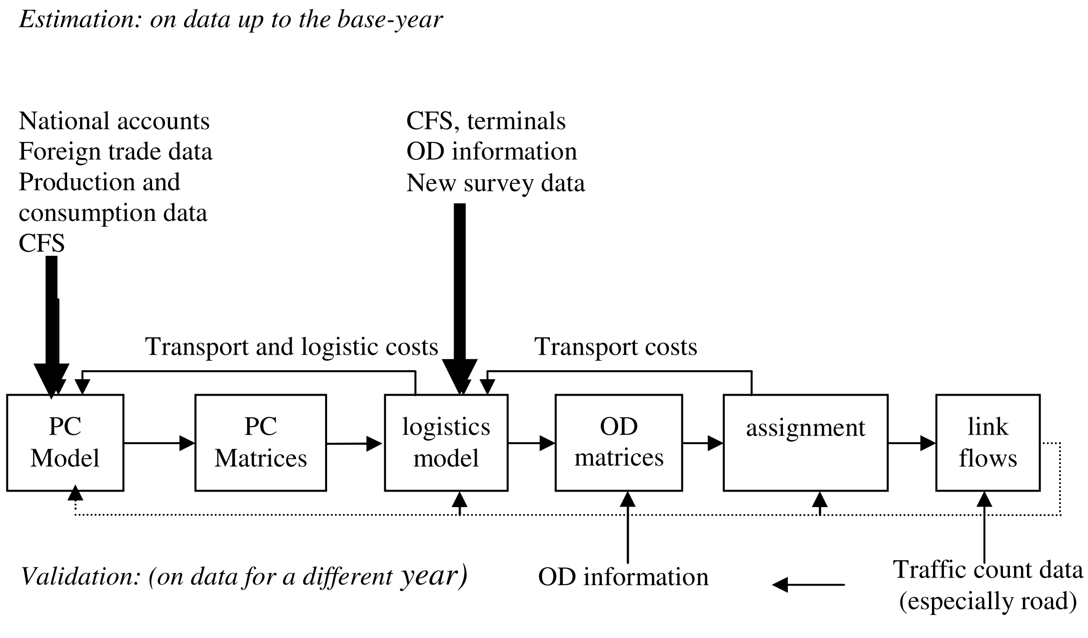

Figure 4. Estimation, calibration and validation of the model systems

The model application process is iterative (see fig. 4, middle and upper part): after assignment, the new generalized costs are used to adjust the PC matrices, etc. This gives rise to an **inner loop,** which functions as follows:

1. The PC models (e.g., MRIO models) provide initial PC matrices;
2. The logistics model transforms these into OD matrices, using transport cost provided by the network model;
3. The network model assigns the OD matrices to the networks;
4. The network model and the logistics model provide transport and logistics costs matrices to the PC model;
5. The PC model produces new base matrices on the basis of the new transport and logistics costs and provides these to the logistics model.

This loop continues until equilibrium is reached (in practice, until a pre-set maximum distance from equilibrium is reached). Estimation is not required within this inner loop. The inner loop addresses the adjustment of model variables (inputs and outputs), not model coefficients.

5.1 Estimation with disagregate data

Data on logistics choices of individual shipments are used in model estimation for step B. The model is based on the total annual logistics costs, such as equation (2). A random cost discrete choice model can be obtained by using total annual logistics costs as the observed component and by adding random cost components ε that follow specific statistical distributions. These random components account for omitted variables, measurement errors and such.

$$C_{mnql} = G_{mnql} + \varepsilon_{mnql} \qquad (3)$$

Where (dropping the subscripts *r* and *s* for the zones and *k* for the modes):
C_{mnql} : total logistic and transport cost
G_{mnql} : observed component of total transport and logistics costs
ε_{mnql} : random cost component.

Using equation (2) for G_{mnql} we get:

$$C_{mnql} = \beta_{0ql} + \beta_1.(Q/q) + X_{mnql} + J_{mnql} + \beta_2.j.v.Q + \beta_3.(t_{mnl}.v.Q)/365 + (\beta_4 + \beta_5.v).(q/2) + a .((LT.\sigma_Q^2)+(Q^2.\sigma_{LT}^2))^{1/2} + \varepsilon_{mnql} \qquad (4)$$

Where:

- β_{0ql} - alternative-specific constant
- β_1 = o
- β_2 = d.g
- β_3 = d (in transit)
- β_4 = w
- β_5 = d (warehousing)

In eq. (4) we included a number of items in the coefficients to be estimated, such as order costs, storage costs and capital carrying costs, because the data on these items can be very difficult to obtain. As a result, the coefficients have specific logistical interpretations. We distinguish between the implied discount rate (*d*) of the inventory in transit (β_3) and of the inventory in the warehouse (β_5), because these need not be the same.

If we assume the extreme value distribution for ε, the model becomes logit. Nested logit is appropriate when some alternatives (e.g., road and rail transport) have a greater degree of substitution than other alternatives (e.g., road and sea transport). This is an empirical question, and statistical tests, particularly likelihood ratio tests, show whether or not the Nested Logit model is justified.

A Logit Mixture Model provides additional flexibility and may be relevant for the logistics model, given the heterogeneity often found in freight transport. Heterogeneity can be captured in two ways:

- Two error components in ε:
  - one following the extreme value distribution;
  - and the other following, for instance, a multivariate normal distribution to allow for flexible correlation structures between alternatives.

- The coefficients in G (the β's) follow a distribution. This is the random coefficients model or tastes variation model. It may capture heterogenious preferences in freight transport decision-making.

5.2 Calibration to aggregate data

In the absence of disaggregate estimation data, it is possible to use a deterministic logistics model. This model can be more easily calibrated with aggregate data (OD information).

Through this ADA model we have developed a procedure to calibrate parameters in the cost function to available aggregate data. A number of calibration parameters (e.g., for implied discount rates, mode-specific constants, constant for direct transport) are added to the cost function. Observed OD data by mode and commodity type for aggregate zones (e.g.,10x10 zones for a country) are used as calibration data. The calibration parameter values are then determined in an iterative process using the procedure described in section 6.

5.3 Validation to traffic count data

The validation process is depicted in figure 4 (bottom part of the figure). After the assignment of the OD flows to the networks, the predicted link flows are compared to observed link flows from traffic counts (especially for road and possibly for rail). Any large discrepancies that may arise require analysis. The parameters in all the models are then recalibrated, employing an iterative procedure. This process creates the **outer loop**. In the outer loop, or model calibration loop, model coefficients in all constituent submodels are adjusted to reach a good match with aggregate data.

6. Application to Norway and to Sweden

The ADA model was specified in a project for Norway and Sweden (RAND Europe et al., 2004). Both countries have model components for deriving PC flows and for network assignment. Prototype versions (version 0) of the logistics model were developed and tested (RAND Europe and Sitma, 2005, 2006, RAND Europe 2006). There are two different models -- one that is part of the Norwegian national freight model system, and one for the Swedish national freight transport forecasting system -- but both have the same structure.

In 2006/2007 a version 1 model was constructed. The logistics cost minimization in this improved deterministic model takes place in two steps. In the first step (transport chain generation), the optimal trans-shipment locations (from the list of available terminals) are determined for each type of transport chain and origin and destination zone. In the second step (transport chain choice), shipment size and transport chain (number of legs, selection of modes and vehicle types) are determined by enumerating all available options for a specific firm-to-firm flow and selecting the one with the lowest logistics costs.

For Norway, the version 1 model uses all firm-to-firm flows based on data on firms by number of employees and municipality. No expansion is needed to determine the population of all goods flows in Norway. For Sweden, though, a sample of firm-to-firm flows (for different size classes) is used for application of the disaggregate logistics choices. After which, an expansion procedure needs to be used to arrive at population totals.

A procedure has been developed to calibrate parameters in the cost function to available aggregate data. A number of calibration parameters (e.g., for implied discount rates, mode-specific constants, constant for direct transport) are added to the cost function. Observed OD data by mode and commodity type for aggregate zones (10x10 zones for a country) are used as calibration data. The calibration parameter values are then determined in an iterative process using the Box-Complex procedure (see Box, 1965, Balakrishna, 2006). This method belongs to the class of direct search methods that do not require derivatives, which is convenient given our highly nonlinear logistics cost function.

Below are results for the version 1 model for Norway, based on assignment of the *P*(W) side in Norway to more than 100,000 firms (senders) and the *C*(W) side to almost 400,000 firms (receivers). There are more receivers than senders because senders can only be firms producing goods or wholesalers, whereas receivers include firms in all sectors (e.g., including services). The number of firm-to-firm flows generated for Norway is 5 mln. This number refers to annual flows (business relationships), each of which can consist of several shipments. The program that was written for the 2006/2007 logistics model, thus, creates a file with 5 mln records. For each of those records is a sending firm (m) in some zone (r), a receiving firm (n) in some zone (s), a commodity type k and an annual total flow Q. The shipment size (and frequency) and transport chain for this flow are determined on the basis of deterministic costs minimization. These results are generated for each firm-to-firm flow (creating a transport chain for every record) and added to the 5 mln firm-to-firm records. The 2006/2007 model, therefore, already is a micro-simulation model. From this large micro-level file, several more aggregate files can be derived. The version 1 model for Norway distinguishes 32 commodity types, about 400 zones (municipalities in Norway, more aggregate zones abroad), transport chains of one, two, three and four legs, ten road vehicle types, 28 vessel types (including ferry), eight train types and two types of aircraft. The distinction between containerized/non-containerized is incorporated by defining container and non-container vehicles and vessel types. The runtime of this version 1 logistics model for Norway was up to 2 hours on a standard PC.

New data collection to enrich the Swedish CFS 2004/2005 and to also obtain disaggregate shipment information for Norway is planned for future years. After which, the disaggregate logistics models will likely be estimated by combining

Norwegian and Swedish datasets and testing, where possible, for differences in behavior.

7. Conclusion

An aggregate-disaggregate-aggregate (ADA) model system for international, national or regional freight transport is presented, including: aggregate models for the determination of goods flows between production and consumption zones (such as input-output models); disaggregate models for logistics decisions, including shipment size, number of legs in the transport chain, use of consolidation and distribution centers and mode; vehicle type and loading unit for each leg; and assignment of the aggregate OD vehicle flows to the networks. The ADA model is specified at the disaggregate level (individual shipments) where disaggregate modeling is feasible and most attractive, but at the aggregate level where disaggregate models are not possible or not attractive because of constraints on available data, software and runtime and for ease of interpretation.

When the middle part of a model system is disaggregate, and the parts that come before and after it are aggregate, additional disaggregation and aggregation steps become necessary. There are many ways to do a disaggregation and the problem has many feasible disaggregate outcomes. Sometimes data are available to determine which solution is most likely, but more often assumptions need to be made as the basis for disaggregation. In all cases, the disaggregation preserves the original PC zone-tozone totals. The aggregation process, however, will have only one solution (though there can be different dimensions to represent the aggregate outcomes, e.g. in tons or in vehicles). Estimation of the disaggregate logistics model described in this paper requires data on individual shipments, which in most countries are not readily available. However, a calibration of such a micro-level model to data at a more aggregate level is also feasible.

In the longer run, an aggregate-disaggregate-disaggregate (ADD model), with assignment of each individual vehicle to the networks, may be possible, though it would likely incorporate a mesoscopic, not a microscopic, assignment. Modeling the international and interregional trade patterns at a disaggregate level (DDD model) may also be possible in the longer run (through choice of supplier by receivers, or the other way around). However, given the nature of the data that are available for this step (trade data from custom records, production and consumption by sector; at best, multi-regional input/output data), aggregate models for PC flows can be expected to remain mainstream.

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Annex I. A method for disaggregation from zone-to-zone flows to firm-to-firm flows of goods.

This approach consists of the following steps (all within step A of the logistics module):

1. Information on the existing distributions of producing and consuming firms (the latter including retail) by commodity type/sector, zone, and size distribution is used. Proportional allocation by size of establishment to assign total supply and demand is carried out.

2. Suppliers are assigned to each receiver. A distribution of the number of suppliers per receiver and a model for the choice of supplier by the receiver are needed. If the information is unavailable, a solution is to go backwards. For instance, the distributions of the number of receivers per supplier and a model for the choice of receiver by the supplier are derived from from the CFS or from industry experts. A supplier can have more than one receiver. Therefore, receiver choice cannot be treated as selecting one receiver from a set of mutually exclusive receiver alternatives. Instead, a binary choice model is developed. A test is applied: will a firm be receiving goods in this category from this supplier? The model should depend on the establishment size. By applying this model a population of supplier/receiver pairs can be generated.

3. Annual tonnage to each supplier-receiver pair is assigned. In step 1 we assign tonnage to each firm by proportional allocation of total supply and demand for the commodity. To obtain starting values, a gravity model is used (i.e., the product of total supply and demand and an exponential of minus a coefficient inversely related to average shipment length multiplied by a generalized cost estimate). All the supplier-receiver pairs that belong to an OD pair from the PWC matrices are collected and the starting values are scaled to match the total flow in the corresponding matrix.

4. Scaling results in distorted P's and C's allocations. To amend this, an iterative step 4 is added to balance total P's and C's by business establishment. This is done as in a doubly constrained gravity model, where the starting values are calculated using modified P's and C's. Step 3 produces consistency with the PWC matrices, but step 4 allows for consistency with the proportional allocations of step 1. Note that the constraints applied should not be hard constraints because they are based on assumptions.